The Force Acting on Band Saw and the Sawing Accuracy

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帯のこにかかる力とひき材精度

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Résumé

In order to clarify the mechanism of the deflection of a band-saw blade in sawing which leads reduction of sawing accuracy taking account of the force acting on the saw blade laterally, three mutually perpendicular components of the force acting on the band saw was measured when sawing a white saraya flitch of 600mm long and the relationship between the force components and the profile of kerf and the effect of the sawing conditions on the maximum lateral deviation of the sawed work were investigated.

Although the force component acting in the cutting direction F_1 and the component in the feed direction F_2 didn't fluctuate largely in sawing, the direction and the magnitude of the lateral component F_3 usually detected at the beginning of the sawing varied as the sawing progressed. The saw-blade deflection caused by the resultant force of F_2 and F_3 at the beginning of the sawing grew as the sawing progressed and produced large deviation of the kerf. This saw-blade deflection was largely effected by F_3 varying due to the inclination of the feed direction to the band saw, the variety of the properties of the flitch and so forth. The reduction of sawing accuracy caused by this saw-blade deflection was notable in sawings at a lower tensile force and/or with the band saw levelled only, that is in sawings with a band saw of low resistance to the lateral deflection. The reason is presently unknown why sawing accuracy was reduced when a thicker flitch was sawed at a higher feed speed. In addition, the effect of the factors other than adopted in this experiment such a grain direction on sawing accuracy became clearer under the condition when sawing accuracy was reduced.

要　　旨

ひき材精度の低下の原因となる帯のこのひき材中のたわみの機構をのこ身に横方向から作用する力に着目して解明するために，長さ 600mm のホワイトセラヤ材をひき材した時の帯のこに作用する力の直交 3 成分を測定し，力の成分とひき道の曲がりの関係とひき材条件のひき曲がり量

への影響を調べた。

帯のこに作用する力の切削方向成分 F_1 と送材方向成分 F_2 のひき材中の変化は小さかったが，横方向成分 F_3 はほとんどの場合にひき材開始時から現れ，その方向と大きさはひき材の進行とともに変化した。のこ身はひき材開始時に F_2 と F_3 の合力によってたわみ，このたわみはひき材の進行とともに増大し大きくひき道をうねらせた。またこのたわみは送材方向ののこ身に対する傾斜や被削材の材質のばらつき等によって変動する F_3 により大きく変化した。ひき材精度の低下は緊張力の低い場合や水平仕上げ処理のみの帯のこのように横方向のたわみに対して帯のこの抵抗が低い場合に顕著であった。またひき幅の大きい材を高速で送材してひき材した場合にひき材精度が低下した原因は明らかにならなかった。さらにひき道の曲がりは被削材の木理方向など本実験で採りあげなかった因子によって，特にひき材精度が低下する条件で大きくばらついた。

1. INTRODUCTION

In sawing with a band saw the force acting on the band saw often deflects the saw blade particularly at a high feed speed and this deflection reduces sawing accuracy. This sawing accuracy must be improved from the viewpoint of reducing wood losses in the subsequent planing and feeding a work at a higher and constant speed.

There have been many studies on sawing accuracy in sawing with a band saw. Many of them discussed this problem from the viewpoint of the buckling of a thin plate loaded axially. That is, when the force acting on a band saw in the feed direction becomes greater than the critical load, the saw blade deflects excessively[1]. However, the effect of the force acting on the saw blade laterally on sawing accuracy should not be overlooked in practical sawing, because this force can easily bend or twist the saw blade in the plane of the less rigidity. Moreover, the force acting on the band saw and the saw-blade deflection in sawing was measured in few of the past studies[2),3)] and the mechanism of the saw-blade deflection has not been clarified yet.

In order to clarify the mechanism of the saw-blade deflection in sawing, the force acting on the band saw was measured taking account of the deflection caused by the lateral force, and the relation between the force components and the saw-blade deflection and the effect of the sawing condition on sawing accuracy was investigated.

2. EXPERIMENT

2.1. Measurement of Force and Sawing Accuracy

The force acting on the band saw in sawing was considered as the reaction force from the work in this experiment and measured by means of a specially designed three-component force transducer of the bonded-strain gages (Figure 1-a). This transducer, that was assembled on the carriage, consisted of a plate on which the work was set and the load sensing-member, four elastic rings. Each ring was made of an aluminum alloy and eight strain gages were bonded on its outer and inner surfaces. Four of them pick up only the strain due to the horizontal force and the others only the strain due to the vertical force according to the theory of elastic rings[4]. By arranging the four rings as shown in Figure 1-a, the three components of the force acting on the band saw, F_1 acting in the

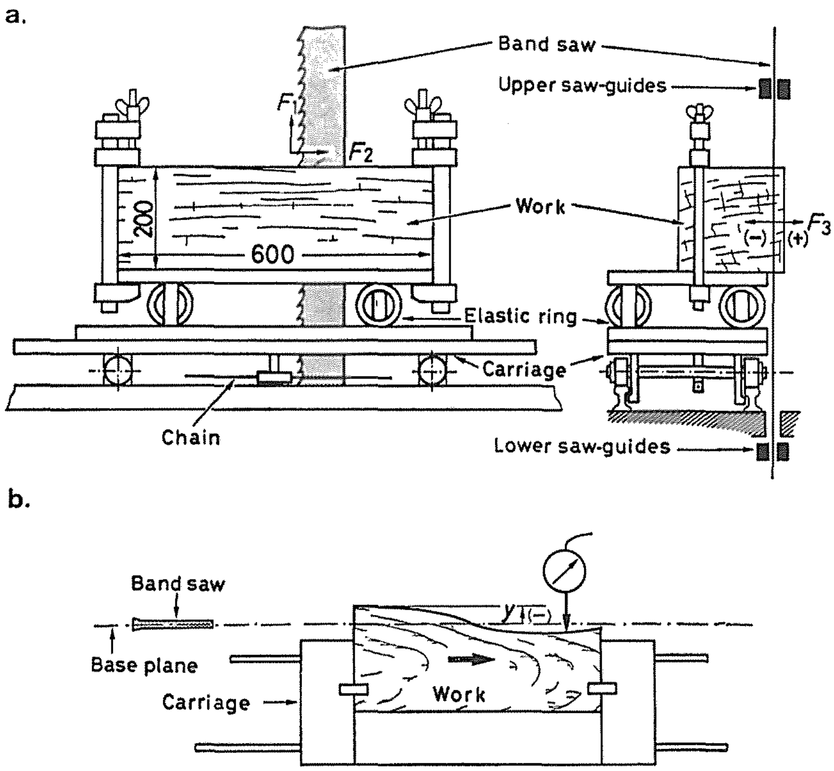

Figure 1. Experimental set-up.
a : Measurement of force, b : Measurement of lateral deviation of sawed work (profile of kerf)
Note : F_1, F_2, F_3 : three components of the force acting on the band saw, y : the lateral deviation of the sawed work from the base plane.

cutting direction, F_2 acting in the feed direction and F_3 acting laterally, can be measured without cross-talk, even when a comparatively large work is sawed. The natural frequencies of the force transducer in sawing were 160Hz in all the three directions.

For the indication of sawing accuacy the lateral deviation of the sawed work from the base plane was measured with a displacement transducer, and from the deviation the profile of kerf was obtained (Figure 1-b).

2.2. Band saws, Workmaterial and Sawing conditions

The work sawed was a white seraya (*Parashorea sp.*) flitch of 600mm long. Several boards of nominal 14mm thickness were sawed from the flitch at a band-saw velocity of 24.8m/s on a band-saw machine whose wheel diameter is 800mm. Six experimental factors were adopted and gathered in Table 1 with their levels and Table 2 shows the specifications of the band saws used. The distance between the upper and the lower saw guides was 560mm and the work was sawed halfway between the upper and the lower wheel-axels. Three or seven boards were sawed from the flitches for each combination of the conditions listed in the Table 1.

3. RESULTS AND DISCUSSION

3.1. Force Variation in Sawing and Profile of kerf

Figure 2 shows that F_1 and F_2 were almost constant in sawing at a feed per tooth of 0.4mm (Figure 2-a), though they showed a slight fluctuatuin probably due to the poor finish of the saw blade and teeth. On the other hand, F_3 varied a little from negative to positive as the sawing progressed. This variation of F_3 became clearer at a feed per tooth of 1.0mm (Figure 2-b). It is found from the behaviors of F_2, F_3 and the profile of kerf that the band saw should have been pushed out by F_3 from its

Table 1. Experimental factors and their levels.

Factors	Levels
Band Saw	A: Levelled only B: Tensioned and back-stretched normally
Tensile force (kgf)	470, 670
Height of work (mm)	50, 100, 150, 200
Distance between the Saw-blade and the saw-guides (mm)	0.25, 0.50, 1.00
Inclination of the feed direction to the band saw (mrad)	2.0, 0.3, 2.0 (for saw A) −0.7, −1.3, −4.9 (for saw B)
Feed speed (m/min) (Feed per tooth (mm))	3, 6, 12, 24, 36, 48, 60 (0.05, 0.1, 0.2, 0.4, 0.6, 0.8, 1.0)

Table 2. Specifications of band saws.

Band saw	Thickness (mm)	Width (mm)	Pitch (mm)	Clearance angle (degrees)	Rake angle (degrees)
A	0.81	94.3	25	22	24
B	0.82	95.0	25	18	24

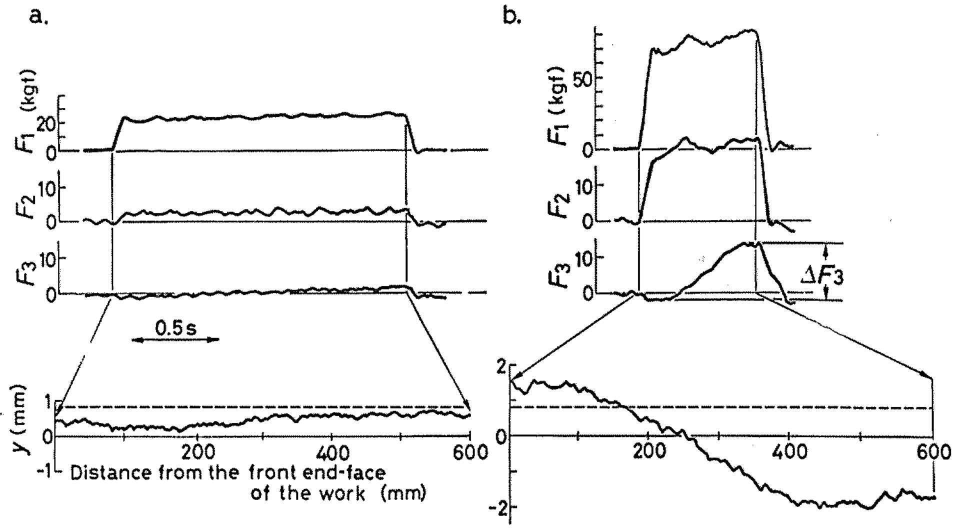

Figure 2. Examples of F_1, F_2, F_3 and profile of kerf (lateral deviation y) for feed per tooth of 0.4mm (left) and 1.0mm (right).
Notes: The lateral deviation y takes positive value when the band-saw blade deflects to the opposite side of the wheels and the broken line denotes the ideal sawed surface when the kerf width is taken into account. ΔF_3 denotes the maximum variation of F_3. Sawing conditions: Band saw B, Height of work 150mm, Tensile force 470kgf.

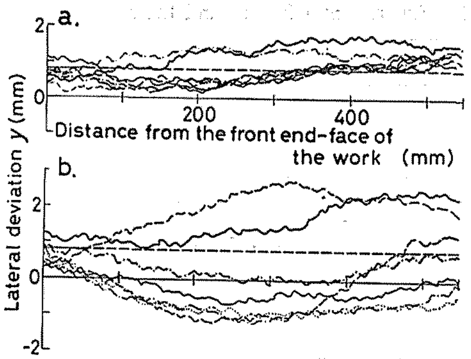

Figure 3. Seven profiles of kerf under the same sawing condition for feed per tooth of 0.6mm (upper) and 1.0 mm (lower) Sawing conditions: Band saw B, Height of work 100 mm, Tensile force 470kgf.

initial position to the outer side, towards the opposite side of the wheels, at the beginning of the sawing, and shifted to the inner side as the sawing progressed and shifted back to its initial position after the sawing. That is, the saw-blade deflection which produced the wound profile of kerf was caused by the resultant force of F_2 and F_3. As Figure 2 shows, F_1 and F_2 increased in sawing when F_3 increased and this can be probably attributed to the friction between the work and the saw blade.

Figure 3 shows seven profiles of kerf under the same sawing condition. The dispersion of the lateral deviations at the beginning of the sawing was probably caused by the lateral vibration of the band saw. At a feed per tooth of 0.6mm (Figure 3-a), the profiles varied a little near the ideal sawed surface and in a similar form except the two upper prifiles above the broken line, which were obtained from a particular flitch. This difference in profiles can be attributed to the difference in properties of the work such a grain direction. In other words, it is considered that the magnitude and the direction of the resultant force of F_2 and F_3 was effected by the variety of the properties of the work and according to this force the saw blade deflected in sawing. At a feed per tooth of 1.0mm (Figure 3-b), though the dispersion of the lateral deviations at the beginnig of the sawing was almost within the same range as at the feed per tooth of 0.6mm, the profiles of kerf were different one another and waved in a wide range. Here also the two upper profiles of kerf above the broken line were remarkably different from others due to the difference in the properties of the work. It was found that the effect of the variety of the work properties became clearer at higher feed speeds.

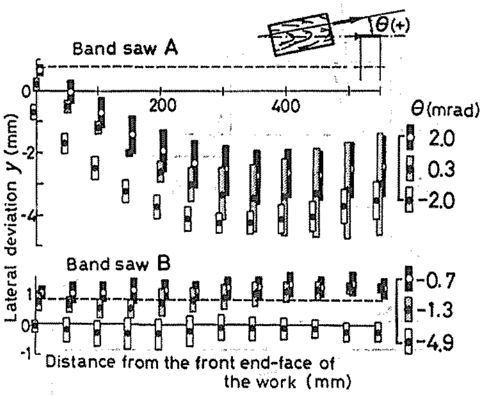

Figure 4. Influence of feed direction on profiles of kerf with saw A and B.
Note: Each plot indicates the mean of the seven measurements and the bar indicates their standard deviation.
Sawing conditions: Height of work 100mm, Tensile force 470kgf, Feed per tooth 0.6mm.

Figure 4 shows the effect of the inclination of the feed direction to the band saw on the profiles of kerf at a feed per tooth of 0.6mm. The profiles produced by band saw A deviated extensively to the inner side and were different at the beginning of the sawing according to the inclination. However, this effect of the inclination on the profiles was not clear in the latter half of the sawing, since the standard deviation at each location increased as the sawing progressed, particularly when the work was fed nearly parallel to the band saw ($\theta=0.3$mrad). Moreover the band saw always deflected toward the inner side for different inclinations and this can be probably attributed to F_3 caused by the poor finish of saw teeth. Not only the lateral deviation but also the standard deviation of each plot for band saw B were smaller than those for band saw A. When the work was fed towards the inner side of the saw blade ($\theta=-4.9$mrad), the plofiles wound somewhat to the inner side and when the work was fed nearly parallel to the saw blade, the ideal sawed surface could be obtained. Moreover, it was confirmed that the direction of F_3 at the beginning of the sawing varied according to the inclination of the feed direction, though the result was not shown in the figures. It is considered that the saw blade was deflected to the inner or the outer side at the touch of the band-saw teeth with the work according to the direction of F_3 varying by the inclination of the feed direction. and this initial deflection of the saw blade had a large influence on the profile of kerf.

Saljé considered that a profile of kerf is influenced by the saw-blade deflection caused by F_3 occurring at the touch of the work with the band saw vibrating laterally.[5] However, it is considered from Figures 3 and 4 that F_3 varying by the inclination of the feed direction, the variety of the properties of the work and probably the poor finish of saw teeth had a large effect on the saw-blade deflection and the consequent profile of kerf.

3.2. Sawing Conditions and Sawing Accuracy

It was found in the former section that the resultant force of F_2 and F_3 deflected saw blade and this deflection reduced sawing accuracy. In this section the influences of the sawing conditions on sawing accuracy are discussed.

Figure 5 shows the influence of tensile force. F_2 increased a little as the feed per tooth increased and there was little difference in F_2 between two tensile forces. On the other hand,the maximum variation of F_3, ΔF_3, and the maximum lateral deviation of the sawed work Y and their range increased as the feed per tooth increased. It should be noted that the reduction of sawing accuracy was confirmed even when F_2 increased little. It found that increase in

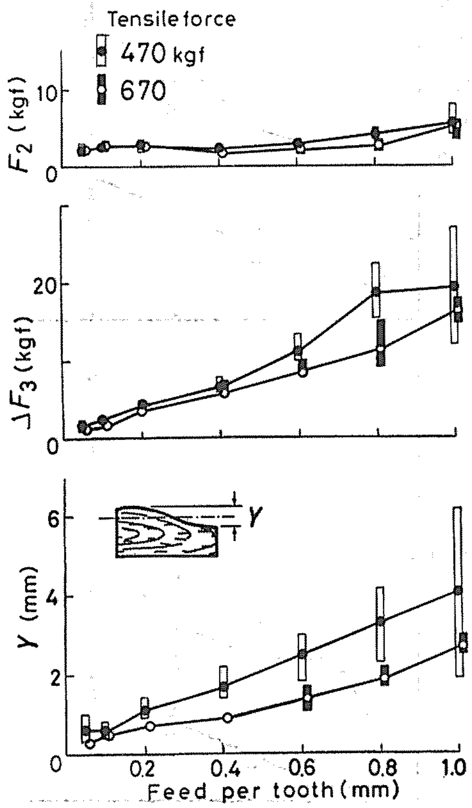

Figure 5. Comparison of F_2, ΔF_3 and maximum lateral deviation Y taking tensile force as a parameter.
Note : Each plot indicates the mean of three measurements and the bar indicates their range, ΔF_3 : see Figure 2.
Sawing conditions : Band saw A, Height of work 100mm.

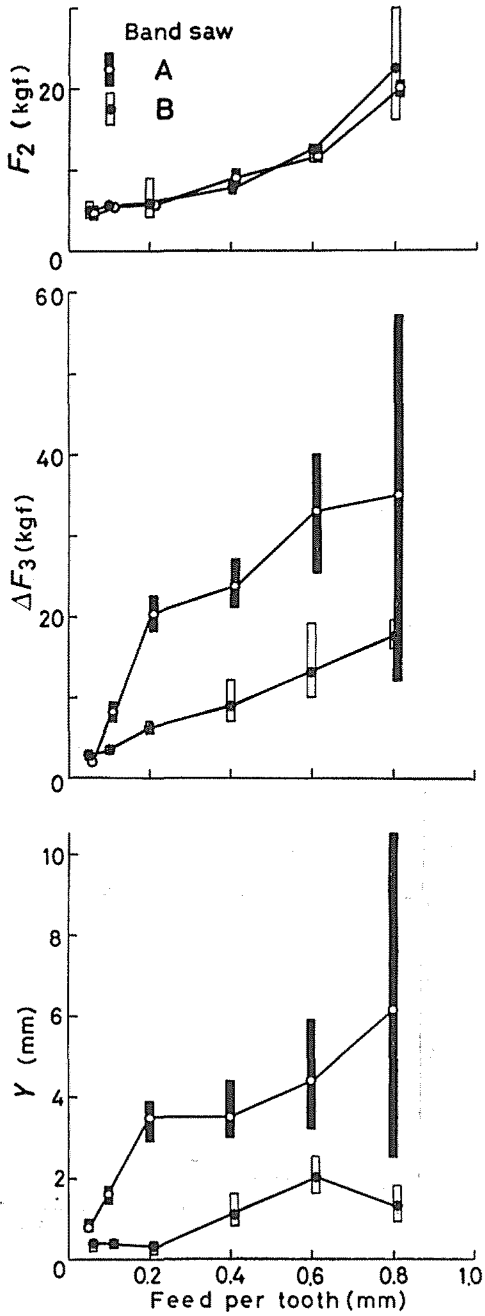

Figure 6. Comparison of F_2, ΔF_3 and maximum lateral deviation Y taking band saw as a parameter.
Note: Same as Figure 5
Sawing conditions: Tensile force 470kgf, Height of work 200mm.

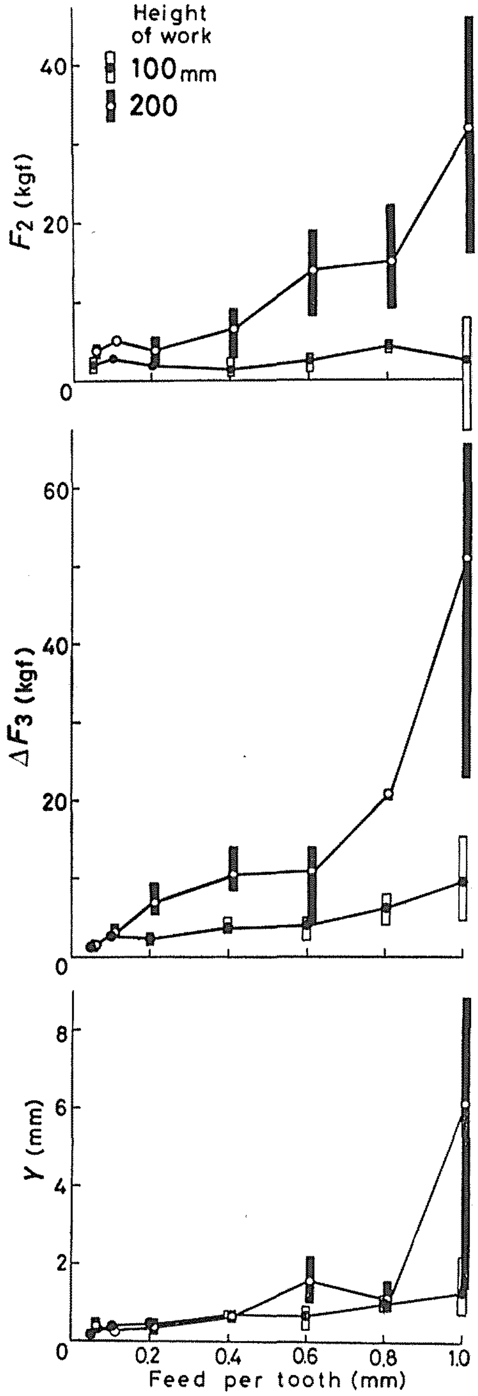

Figure 7. Comparison of F_2, ΔF_3 and maximum lateral deviation Y taking height of work as a parameter.
Note: Same as Figure 5
Sawing conditions: Band saw B, Tensile force 470kgf.

tensile tforce, that is increase in the resistance of the saw blade to the bending or torsional deflection could improve sawing accuracy.

Similarly it can be probably attributed to an increase in the resistance of band saw B by tensioning or back-stretching that the maximum lateral deviation for band saw B was smaller than that for band saw A, though the finish of saw teeth was not investigated fully in this experiment (Figure 6). However, it is important to investigate the effect of the saw teeth with broken tips or unsymmetrical swage-set on F_3 and sawing accuracy, as St-laurent reported[6].

Figure 7 shows the influence of height of work. F_2, ΔF_3 and the maximum lateral deviation Y were remarkably large at a feed per tooth of 1.0mm and dispersed widely, particularly for the work of 200mm high. It is considered that saw dust should have also influenced on the saw-blade deflection in sawing.

Figure 8 shows the influence of the distance between the saw blade and the saw guides on the maximum lateral deviation Y. The maximum lateral deviation was larger at the distance of 0.50mm than at 0.25mm. This became clearer as the feed per tooth increased. On the other hand, there was no remarkable increase in the maximum lateral deviation at the distance of 1.0mm. It was found that saw guides were less effective against the saw-blade deflection when they were set farther than by 0.50mm away from the saw blade.

In order to summerize the influences of the sawing conditions on the maximum lateral deviation, an analysis of variancewas carried out and the result is shown in Table 3. Factors such as band saw, height of work and particularly feed per tooth had influenced on the maximum lateral deviation. The band saw

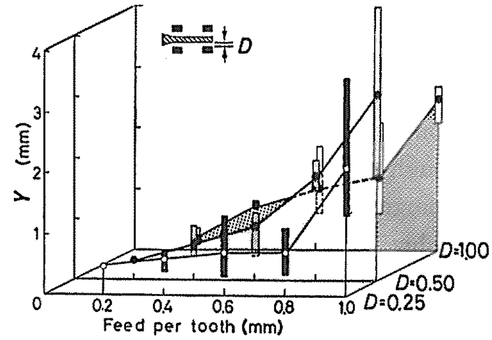

Figure 8. Influence of distance between saw blade and saw guides on maximum lateral deviation.
Note: Same as Figure 5
Sawing condition: Band saw B, Height of work 150mm, Tensile force 470kgf.

Table 3. Analysis of variance for the Maximum lateral deviation.

Factor	Degrees of freedom		Ratio of contribution (%)
A: Band saw	1	**	19.2
B: Feed per tooth	5	**	26.4
C: Tensile force	1	*	0.7
D: Height of work	1	**	8.8
A × B	5	**	8.0
A × C	1		
A × D	1	**	6.3
B × C	5		
B × D	5	**	3.2
C × D	1		
Interaction among 3 or 4 factors	21	*	3.6
Error	96		23.8

which was tensioned and back-stretched would not be deflected easily by the resultant force of F_2 and F_3 because of its high resistance to the deflection. The reason was not clarified from the result why F_2, F_3 and the consequent saw-blade deflection became larger, when a thicker work was sawed at a higher feed speed. In addition, the ratio of error, that is the effect of the factors other than adopted in this experiment such a properties of work on the analysis was large. It was also found from the increase in the range of F_2, F_3 and the maximum lateral deviation Y that the effect of these factors became clearer under a condition when sawing accuracy lowered.

4. CONCLUSION

It became clear from this experimental results that the band-saw blade was deflected by the resultant force of F_2 and F_3 in sawing and this deflection produced a wound profile of kerf. The effect of F_3 on the saw-blade deflection was particularly large, since it can easily bend or twist the saw blade largely acting in the plane of the less rigidity. Moreover F_3 was influenced by many factors such as the variety of the work properties, the inclination of the feed direction to the saw blade, and probably the finish of the saw teeth. Although the saw-blade deflection, once had happend, grew larger and larger as the sawing progressed, this deflection can be lessened by tensiling the band saw strongly or by tensioning or back-stretching of the saw blade, that is by increasing in the resistance to the saw-blade deflection caused by F_2 and F_3. The reason is presently unknown why the sawing accuracy was reduced and the effect of the factors such a variety of the work properties on sawing accuracy became clearer when a thicker work was sawed at a higher feed speed.

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